

UNITED STATES PATENT APPLICATION

FOR

SUBSCRIBER LINE INTERFACE CIRCUITRY

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## SUBSCRIBER LINE INTERFACE CIRCUITRY

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of application number 09/298,008 of Hein, et al., filed April 22, 1999.

### 5 FIELD OF THE INVENTION

This invention relates to the field of telecommunications. In particular, this invention is drawn to subscriber line interface circuitry.

### BACKGROUND OF THE INVENTION

Subscriber line interface circuits are typically found in the central office  
10 exchange of a telecommunications network. A subscriber line interface circuit (SLIC) provides a communications interface between the digital switching network of a central office and an analog subscriber line. The analog subscriber line connects to a subscriber station or telephone instrument at a location remote from the central office exchange.

15 The analog subscriber line and subscriber equipment form a subscriber loop. The interface requirements of an SLIC typically result in the need to provide relatively high voltages and currents for control signaling with respect to the subscriber equipment on the subscriber loop. Voiceband communications are typically low voltage analog signals on the subscriber  
20 loop. Thus the SLIC must detect and transform low voltage analog signals into digital data for transmitting communications received from the subscriber equipment to the digital network. For bi-directional communication, the SLIC must also transform digital data received from the digital network into low voltage analog signals for transmission on the  
25 subscriber loop to the subscriber equipment.

One SLIC design includes discrete passive inductive components such as transformers for handling the higher voltages and currents. Disadvantages of this design include the bulkiness, weight, and power consumption of the passive inductive components.

- 5 Another SLIC design incorporates multiple specialized integrated circuits to achieve a transformerless SLIC. Typically one integrated circuit is dedicated to handling the low voltage digital signaling and another integrated circuit is dedicated to handling the higher powered analog control signaling functions required for the subscriber loop. One disadvantage of this design is
- 10 that programming of various SLIC operational characteristics is typically accomplished using discrete components such that the SLIC operational characteristics are not dynamically modifiable. In addition, the integrated circuit handling the higher powered analog control signaling functions tends to be relatively expensive.

## SUMMARY OF THE INVENTION

In view of limitations of known systems and methods, a subscriber line interface circuit is described. In one embodiment, the subscriber line interface circuit apparatus includes a signal processor having sense inputs for sensed tip and ring signals of a subscriber loop. The signal processor calculates common mode and differential mode components of the subscriber loop. The signal processor generates linefeed driver control signals in response to the sensed signals. The signal processor resides on an integrated circuit die. In one embodiment, the linefeed driver consists of discrete components.

In another embodiment, a subscriber line interface circuit apparatus includes a signal processor generating subscriber loop control signals in response to sensed tip and ring signals from the subscriber loop. A linefeed driver portion drives the subscriber loop in accordance with the subscriber loop control signals. The linefeed driver portion provides the sensed tip and ring signals. Each of the linefeed driver portion and the signal processor resides on an integrated circuit die. In one packaging implementation, the signal processor and the linefeed driver portion reside on separate integrated circuit die within separate integrated circuit packages. In another packaging implementation, the signal processor and linefeed driver portion reside on separate integrated circuit die within the same integrated circuit package. In yet another packaging implementation, the signal processor and the linefeed driver portion reside on the same integrated circuit die. The common mode and differential mode components of the subscriber loop are calculated by the signal processor rather than the linefeed driver regardless of packaging implementation.



### BRIEF DESCRIPTION OF THE DRAWINGS

The present invention is illustrated by way of example and not limitation in the figures of the accompanying drawings, in which like references indicate similar elements and in which:

Figure 1 illustrates one embodiment of a central office exchange including a subscriber line interface circuit (SLIC) coupling subscriber equipment to a digital switching system.

Figure 2 illustrates a block diagram of an SLIC including a signal processor and a linefeed driver.

10 Figure 3 illustrates one embodiment of an SLIC linefeed driver.

Figure 4 illustrates a block diagram of an alternative embodiment of the SLIC.

Figures 5(a)-5(d) illustrate various packaging embodiments for the signal processor and linefeed driver.

15 Figure 6 illustrates alternative applications of the SLIC.

## DETAILED DESCRIPTION

Figure 1 illustrates functional elements of one embodiment of a subscriber line interface circuit (SLIC) 110 typically associated with plain old telephone services (POTS) telephone lines. The subscriber line interface circuit (SLIC) provides an interface between a digital switching network 120 of a local telephone company central exchange and a subscriber loop 132 including subscriber equipment 130.

The subscriber loop 132 is typically used for communicating analog data signals (e.g., voiceband communications) as well as subscriber loop "handshaking" or control signals. The analog data signals are typically on the order of 1 volt peak-to-peak (i.e., "small signal"). The subscriber loop control signals typically consist of a 48 V d.c. offset and an a.c. signal of 40-140 Vrms (i.e., "large signal"). The subscriber loop state is often specified in terms of the tip 180 and ring 190 portions of the subscriber loop.

The SLIC is expected to perform a number of functions often collectively referred to as the BORSCHT requirements. BORSCHT is an acronym for "battery feed," "overvoltage protection," "ring," "supervision," "codec," "hybrid," and "test."

The SLIC provides power to the subscriber equipment 180 using the battery feed function. The overvoltage protection function serves to protect the central office circuitry against voltage transients that may occur on the subscriber loop 132. The ring function enables the SLIC to signal the subscriber equipment 180. In one embodiment, subscriber equipment 180 is a telephone. Thus, the ring function enables the SLIC to ring the telephone.

The supervision function enables the SLIC to detect service requests such as when the caller goes off-hook. The supervision function is also used to supervise calls in progress and to detect dialing input signals.

5 The hybrid function provides a conversion from two wire signaling to four wire signaling. The SLIC includes a codec to convert the four-wire analog voiceband data signal into serial digital codes suitable for transmission by the digital switching network 120. In one embodiment, pulse code modulation is used to encode the voiceband data. The SLIC also typically provides a means to test for or to indicate faults that may exist in the  
10 subscriber loop or the SLIC itself.

The codec function has relatively low power requirements and can be implemented in a low voltage integrated circuit operating in the range of approximately 5 volts or less. The battery feed and supervision circuitry typically operate in the range of 40-75 volts. In some implementations the  
15 ringing function is handled by the same circuitry as the battery feed and supervision circuitry. In other implementations, the ringing function is performed by higher voltage ringing circuitry (75 - 150 V<sub>rms</sub>). Thus depending upon implementation, the ringing function as well as the overvoltage protection function may be associated with circuitry having  
20 greater voltage or current operating requirements than the other circuitry.

Recent transformerless SLIC designs tend to distribute the functional requirements between two integrated circuits based on whether the functions are traditionally associated with the high voltage subscriber loop controls or the low voltage data processing. For example, in one embodiment, the codec  
25 is implemented in a low voltage integrated circuit and the remaining



functions (e.g., supervision) are implemented primarily in a high voltage integrated circuit such as a bipolar integrated circuit. Although this design tends to offer considerable space, weight, and power efficiencies over designs requiring passive inductive components, this distribution of the functional requirements tends to result in a relatively expensive high voltage integrated circuit.

Figure 2 illustrates one embodiment of an SLIC 200 wherein the BORSCHT functions have been redistributed between a signal processor 210 and a linefeed driver 220. Signal processor 210 is responsible for at least the ring control, supervision, codec, and hybrid functions. Signal processor 210 controls and interprets the large signal subscriber loop control signals as well as handling the small signal analog voiceband data and the digital voiceband data.

In one embodiment, signal processor 210 is an integrated circuit. The integrated circuit includes sense inputs for a sensed tip and ring signal of the subscriber loop. The integrated circuit generates subscriber loop linefeed driver control signal in response to the sensed signals. In one embodiment, the linefeed driver does not reside within the integrated circuit or within the same integrated circuit package as the signal processor 210. In alternative embodiments, the signal processor may reside within the same integrated circuit package as at least a portion of the linefeed driver.

Signal processor 210 receives subscriber loop state information from linefeed driver 220 as indicated by tip/ring sense 222. This information is used to generate control signals for linefeed driver 220 as indicated by linefeed driver control 212. The voiceband 230 signal is used for bi-directional

communication of the analog voiceband data between linefeed driver 220 and signal processor 210.

Signal processor 210 includes a digital interface for communicating digitized voiceband data to the digital switching network using digital

5 voiceband 216. In one embodiment, the digital interface includes a processor interface 214 to enable programmatic control of the signal processor 210. The processor interface effectively enables programmatic or dynamic control of battery control, battery feed state control, voiceband data amplification and level shifting, longitudinal balance, ringing currents, and other subscriber  
10 loop control parameters as well as setting thresholds such as a ring trip detection thresholds and an off-hook detection threshold.

The digital voiceband data 214 is coupled to a digital codec interface of signal processor 210 for bi-directional communication of the digital voiceband data between the codec of the signal processor and the digital switching  
15 network. The analog voiceband data 230 is coupled to an analog codec interface of signal processor 210 for bi-directional communication of the analog voiceband data between the codec and the linefeed driver.

Linefeed driver 220 maintains responsibility for battery feed to tip 280 and ring 290. Overvoltage protection is not explicitly illustrated, however,  
20 overvoltage protection can be provided by fuses incorporated into linefeed driver 220, if desired. Linefeed driver 220 includes sense circuitry to provide signal processor 210 with pre-determined sensed subscriber loop operating parameters as indicated by tip/ring sense 222. Signal processor 210 performs any necessary processing on the sensed parameters in order to determine the  
25 operational state of the subscriber loop. For example, differences or sums of

sensed voltages and currents are performed as necessary by signal processor 210 rather than linefeed driver 220. Thus common mode and differential mode components (e.g., voltage and current) of the subscriber loop are calculated by the signal processor rather than the linefeed driver.

5           Linefeed driver 220 modifies the large signal tip and ring operating conditions in response to linefeed driver control 212 provided by signal processor 210. This arrangement enables the signal processor to perform processing as needed to handle the majority of the BORSCHT functions. For example, the supervisory functions of ring trip, ground key, and off-hook  
10       detection can be determined by signal processor 210 based on operating parameters provided by tip/ring sense 222.

          Figure 3 illustrates one embodiment of an SLIC linefeed driver 300. In one embodiment, the linefeed driver 300 is implemented as a number of discrete components. Linefeed driver 300 includes a voiceband circuitry 320,  
15       sensing circuitry 330, and power circuitry 340.

          Voiceband circuitry 320 enables data signals corresponding to voiceband communications to be retrieved from or impressed onto the subscriber loop. Capacitors CR and CT effectively provide a.c. coupling for the analog voiceband data from the subscriber loop to the signal processor while  
20       decoupling signal processor 210 from the d.c. offsets of the tip 380 and ring 390 nodes. Thus capacitors CR and CT effectively provide d.c. isolation of the analog voiceband data interface formed by nodes 322-328 from the subscriber loop. In the embodiment illustrated, voiceband circuitry 320 provides a.c. coupling of the analog voiceband data between the subscriber loop and the  
25       signal processor using only passive components.

Voiceband communication is bi-directional between the subscriber loop and signal processor 210. Nodes 324 and 328 serve to communicate voiceband data from the subscriber loop to signal processor 210 (i.e., tip and ring "audio in"). Nodes 322 and 326 provide a means of impressing a signal on the subscriber loop from signal processor 210 (i.e., tip and ring "audio out"). In one embodiment RTT and RTR collectively establish a 600  $\Omega$  termination impedance.

Sensing circuitry 330 enables signal processor 210 to determine the tip 380 and ring 390 node voltages as well as the subscriber loop current using sensing resistors RS1, RS2, RS3, and RS4. Resistors RT and RR are used to generate a voltage drop for determining the tip and ring currents. In one embodiment, sensing circuitry 330 consists only of passive discrete components.

Referring to Figure 2, tip/ring sense 222 includes a sensed tip signal and a sensed ring signal. In one embodiment, the sensed tip signal includes first and second sensed tip voltages. Resistors RS1 and RS2 are used to sense the tip line voltage at each end of RT. Resistors RS1 and RS2 convert the sensed tip line voltages to currents suitable for handling by signal processor 210 at nodes 332 and 334. The difference between the first and second sensed tip voltages is proportional to the tip current. Likewise, the sensed ring signal includes first and second sensed ring voltages. Resistors RS3 and RS4 similarly convert sensed ring line voltages at both ends of RR to currents suitable for handling by signal processor 210 at nodes 336 and 338. The difference between the first and second sensed ring voltages is proportional to the ring current. These calculations, however, can be performed as necessary

by the signal processor 210 rather than the linefeed driver 220 circuitry. In addition, these sensed parameters enable the signal processor 210 to determine the subscriber loop voltage and the subscriber loop common mode and differential mode currents.

5        Power circuitry 340 provides the battery feed and other relatively high voltage functions to the subscriber loop in accordance with analog linefeed control signals provided by the signal processor 210 at nodes 342, 344, 346, and 348. Processing of the sensed parameters of the tip and ring lines for generating the linefeed control signals is handled exclusively by signal  
10       processor 210.

      The subscriber loop current and the tip and ring voltages are controlled by transistors Q1-Q6. In one embodiment, Q1-Q4 are PNP bipolar junction transistors and Q5-Q6 are NPN bipolar junction transistors. Given that the base terminals of Q1-Q4 are coupled to ground, nodes 342-348 need only be  
15       approximately 0.7 volts to turn on transistors Q1-Q4. Due to the small voltage drop between the base and emitters of Q1-Q4, control of the linefeed circuitry requires relatively low power and thus linefeed driver control currents I1-I4 may be provided by a signal processor 210 implemented as a low voltage complementary metal oxide semiconductor (CMOS) integrated circuit.

20       Transistors Q1, Q4, and Q6 (and resistor R2) control the tip voltage 380. The tip voltage is increased by the application of control current I1 to Q1. The tip voltage (node 380) is decreased by the application of control current I4 to Q4. Thus control currents I1 and I4 effectively provide a tip control signal for manipulating the tip voltage at node 380.

Similarly, transistors Q2, Q3, and Q5 (and resistor R1) control the ring voltage 390. The application of control current I3 to Q3 increases the ring voltage. The ring voltage is decreased by the application of control current I2 to Q2. Control currents I2 and I3 effectively provide a ring control signal for  
5 manipulating the ring voltage at node 390.

Control currents I1-I4 thus effectively control the large signal subscriber loop current and tip and ring voltages. For example, the ringing signal can be generated by using the control signals at nodes 342-348 to periodically reverse the polarity of tip 380 with respect to ring 390 (i.e., battery polarity reversal) at  
10 the nominal ringing frequency.

Sensing portion 330 enables signal processor 210 to determine the large signal state of the subscriber loop without the need for intervening active circuitry or level shifters. In one embodiment, sensing portion 330 comprises only passive discrete components. The linefeed control inputs 342-348 enable  
15 signal processor 210 to actively manage the large signal state of the subscriber loop. In particular, the large signal a.c. and d.c. components of the subscriber loop control protocol can now be controlled directly by a low voltage integrated circuit. The large signal a.c. and d.c. control loops are effectively terminated at the signal processor 210.

In other words, the large signal a.c. and d.c. control loops are  
20 terminated at the low voltage integrated circuit. Thus signal processing and state determination such as off-hook, ring trip, and ring control formerly associated with high power analog circuitry can be handled predominately by a low voltage integrated circuit. In addition, the integrated circuit signal  
25 processor can handle processing of the small signal analog voiceband data

from the subscriber loop without the need for intervening active elements or level shifting circuitry.

Figure 4 illustrates a block diagram of an alternative embodiment of an SLIC. Comparing Figure 4 with Figure 2, the primary difference is that a portion of the voiceband communication function (230) is handled by the same signal lines handling the linefeed driver control (212). In particular, signal lines 412 combine the linefeed driver control function with transmission of voiceband communications from the signal processor 410 to the linefeed driver 420 (i.e., audio out) for communication to the subscriber equipment.

Referring to Figure 3, this is accomplished in one embodiment by superimposing the a.c. voiceband communications on the control currents I1 and I4. The bi-directional voiceband data interface includes nodes 324, 328, 342, and 348. Accordingly resistors RTT and RTR are eliminated in this configuration thus reducing the number of discrete components. Another advantage of this configuration is that the termination impedance previously determined by the values of RTT and RTR can now be set by controlling currents I1-I4. The use of a programmable signal processor 410 effectively places the value of the termination impedance formerly determined by RTT and RTR under programmatic control.

Figure 5 illustrates various packaging arrangements for a signal processor and linefeed driver. For example, in one embodiment the signal processor is an integrated circuit and the linefeed driver comprises a plurality of discrete components as illustrated in Figure 5(a).

In Figure 5(b), the signal processor 510 and at least a portion 520 of the linefeed driver are distinct integrated circuit packages such that fewer discrete components 530 are required. Referring to Figure 3, in one embodiment the integrated circuit portion 520 of the linefeed driver includes power circuitry 340. In an alternative embodiment the integrated circuit portion 520 of the linefeed driver includes linefeed driver power circuitry 340 and the tip and ring sense circuitry 330. In these embodiments, the tip and ring voiceband data components 320 remain as discrete components 530.

Figures 5(c) and 5(d) illustrate incorporation of a signal processor 510 and a linefeed driver portion within the same integrated circuit package 512. In Figure 5(c), the signal processor and the linefeed driver portion are located on separate dies (510, 520) within the same integrated circuit package 512. In one embodiment, the line driver integrated circuit portion 520 includes the power circuitry. In another embodiment, the linefeed driver integrated circuit portion includes the power circuitry and the sense circuitry.

In Figure 5(d), a signal processor and a linefeed driver portion are located on the same die 510 (e.g., having a common semiconductor substrate) within a single integrated circuit package 512. In one embodiment, the line driver integrated circuit portion of the die 510 includes the power circuitry. In another embodiment, the linefeed driver integrated circuit portion of die 510 includes the power circuitry and the sense circuitry.

Referring to Figures 3 and 5, the audio portion 320 of the linefeed driver circuitry will remain as discrete components in one embodiment. Thus the discrete components 530 of Figures 5(a)-5(d) includes the tip and ring audio circuitry 320.



The central telephone exchange described above is merely one example of an SLIC application communicating with subscriber equipment using the POTS ("plain old telephone system") interface. Other SLIC applications include private exchanges and "zero loop" applications.

5       Zero loop applications often have a relatively short distance subscriber loop between the subscriber equipment and the SLIC. This is often the case when subscriber equipment must interface with a non-POTS systems such as a network that uses different communication media or protocols.

10       Figure 6 illustrates various zero loop applications for the SLIC. In one embodiment, the SLIC 612 is used in an Integrated Services Digital Network (ISDN) modem 610. ISDN modem 610 provides bi-directional communication between subscriber equipment 614 and the ISDN network 616. In another embodiment, SLIC 622 is used in cable modem 620. In one embodiment, cable modem 620 communicates information using the  
15       community antenna television (CATV) network 616. SLIC 622 enables cable modem 620 to communicate information from the coaxial CATV cable 626 to subscriber equipment 624. In another example, digital subscriber line (DSL) modem 630 incorporates a SLIC 632 for communication between digital subscriber line 636 and subscriber equipment 634 having a POTS interface.  
20       Another example includes wireless applications such as wireless modem 640.

      Given the widespread availability of subscriber equipment with a POTS interface and support for that interface, manufacturers are likely to continue to need to provide POTS compatible subscriber equipment even as the number of non-POTS communication services expands. Accordingly, the  
25       number of zero loop applications tends to grow with the number of

non-POTS communications services in order to capitalize on the installed base of POTS compatible subscriber equipment.

Unlike the central exchange applications, the zero loop applications may enable the design of SLICs having relaxed performance characteristics. In

5 particular, the zero loop application SLIC need not necessarily meet typical POTS standards if the subscriber equipment is not actually connected to the public telephone network. In such cases, the SLIC need only meet the minimum operational requirements of the subscriber equipment POTS interface. For example, the ringing function may be provided by periodic  
10 polarity reversal of the battery feed rather than a separate higher voltage ringing generator. Relaxation of other constraints may result in further simplification of the circuitry.

In the preceding detailed description, the invention is described with reference to specific exemplary embodiments thereof. Various modifications  
15 and changes may be made thereto without departing from the broader spirit and scope of the invention as set forth in the claims. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense.